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(54) Title: OPTICAL ISOLATOR

(57) Abstract

An optical isolator (10) having a constitution in which a Faraday rotator (3) is sandwiched by two polarizers (1, 2), which can be more easily produced at a reduced cost. An optical isolator is constituted so that it comprises the following constituent elements in the described order: a first reflection–type polarizer (1) made of a polymeric multilayer film; a Faraday rotator (3) capable of rotating the polarizing plane by 45 degrees; a tapered glass plate (4); and a second reflection–type polarizer (2) made of a polymeric multi–layer film.

OPTICAL ISOLATOR

5   <u>BACKGROUND</u>

The present invention relates to an optical circuit
element and, more particularly, to an optical isolator which
permits light to transmit in a predetermined direction only
10   in an optical communication equipment, optical data
equipment and similar equipment.

An optical isolator typically comprises a Faraday rotator
applied with a magnetic field capable of rotating the
15   polarizing plane of incident light by 45 degrees, and two
polarizers sandwiching the Faraday rotator from both sides,
i.e., from the light incident side and from the light
emerging side. Such an optical isolator exhibits a low loss
in the forward direction in which light travels from the
20   incident side to the emerging side, and exhibits a large
loss in the reverse direction in which light returns from
the emerging side back to the incident side. Thus, the
optical isolator exhibits a function for transmitting light
in one direction only, shutting off the transmission of
25   light in the reverse direction.

Optical isolators of various types have heretofore been
known. For instance, Japanese Examined Utility Model
Publication (Kokoku) No. 7-17057 discloses an optical
30   isolator constituted by a Faraday rotator which is a
parallelepiped having an end surface on the incident side
tilted relative to the optical axis and rotates, by 45
degrees, the polarizing plane of emerging light of a
semiconductor laser, and a polarizing/isolating film formed

on the end surface on the emerging side of the Faraday
rotator. The polarizing/isolating film exhibits a
polarizing/isolating property which permits the P waves to
pass through but reflects the S waves, and can be formed by
5   alternatingly laminating dielectric films having different
refractive indexes and having a predetermined thickness one
upon the other.

In the conventional optical isolators, the polarizer is
10   made up of the polarizing/isolating film formed by
laminating dielectric layers, as well as a polarized beam
splitter, a polarizing glass, and a birefringent single
crystal. However, these polarizers are all made from
expensive starting materials, and require working steps such
15   as cutting, polishing, etc., and are inevitably accompanied
by complex production steps and increased production costs.
In fact, the cost of producing the polarizer is about 50%
of the total cost for manufacturing the conventional optical
isolator. It has therefore been urged to lower the cost of
20   producing the polarizer in the production of optical
isolators.

One of the objects of the present invention is to provide
an optical isolator which can be easily produced, while
25   maintaining a good yield and a low cost, yet exhibiting an
insertion loss and a reverse loss comparable to those of the
conventional optical isolators.

Summary of the Invention

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In one embodiment thereof, the present invention relates
to an optical isolator comprising the following elements in
the described order:

2

a first reflection-type polarizer made of a polymeric multilayer film;

a Faraday rotator capable of rotating a polarizing plane by 45 degrees;

5   a tapered glass plate; and

a second reflection-type polarizer made of a polymeric multi-layer film.

In another embodiment thereof, the present invention
10   resides in an optical isolator comprising the following constituent elements in the described order:

a first reflection-type polarizer made of a polymeric multilayer film;

a tapered Faraday rotator; and

15   a second reflection-type polarizer made of a polymeric multi-layer film.

In these optical isolator embodiments of the present invention, the constituent elements are preferably joined
20   and integrally secured together with an adhesive or similar joining means.

Description of the Drawings

25   Fig. 1 is a sectional view illustrating an optical isolator according to a first embodiment of the present invention.

Fig. 2   is a sectional view illustrating the paths
30   of transmission light through the optical isolator of Fig. 1.

Fig. 3 is a graph illustrating the optical characteristics of the optical isolator of Fig. 1.

Fig. 4 is a sectional view illustrating the optical isolator according to a second embodiment of the present invention.

5

Basically, the optical isolator according to the present invention has a constitution similar to that of the conventional optical isolator. That is, the optical isolator according to the present invention is constituted,
10   at least, by a Faraday rotator capable of rotating the polarizing plane by 45 degrees, and two polarizers sandwiching the Faraday rotator from both sides, i.e., from the light incident side and from the light emerging side.

15   The two polarizers used in the optical isolator of the present invention are, respectively, the reflection-type or reflective polarizers made of a polymeric multi-layer film and are, preferably, used in the form of polarizing films. From the standpoint of distinction, the polarizer arranged
20   on the light incident side is called first polarizer, and the polarizer arranged on the light emerging side is called second polarizer. In the following description, the polarizers of the present invention are particularly described with reference to the reflection-type polarizing
25   film.

The reflection-type polarizing film that is preferably used for carrying out the present invention is a multi-layer optical film disclosed in Japanese Unexamined Patent
30   Publication (Kokai) No. 9-507308. As described in the publication, this multi-layer film is obtained by alternatingly laminating two kinds of different polymers "A" and "B" one upon the other. That is, the obtained multi-layer film has a structure in which the layers are laminated

in order of --- A B A B ---. This multi-layer film is drawn
along an axis (X-axis) at a drawing ratio of about 5:1 but
is not drawn along another axis (Y-axis at right angles with
Xaxis). Therefore, the multi-layer film is drawn along the
5   Y-axis substantially at a drawing ratio of 1:1. In this
specification, the X-axis is described as "drawing
direction" and the Y-axis is described as "transverse
direction".

10   In producing the above-mentioned multi-layer film, the one
polymer "B" has an apparent refractive index (e.g., 1.64)
which does not substantially change depending upon the
drawing or, in other words, which is optically isotropic.
The other polymer "A" is the one of which the refractive
15   index changes depending upon the drawing process. For
example, the monoaxially drawn sheet of the polymer "A"
exhibits a first refractive index (e.g., 1.88) in the
direction of drawing and a second refractive index (e.g.,
1.64) in the transverse direction.

20

In the polymeric multi-layer film refractive index related
to the in-plane axis (in parallel with the surface of the
film) is defined to be an effective refractive index
relative to the plane-polarized incident light, and the
25   polarizing plane is in parallel with the in-plane axis.
Therefore, after being drawn, the multi-layer film --- A B A
B --exhibits a large difference in the inter-layer
refractive index (1.88 to 1.64) in the direction of drawing,
but exhibits substantially the same inter-layer refractive
30   index in the transverse direction. Accordingly, the multi-
layer film can work as a reflection-type polarizing film
capable of propagating polarized components of incident
light. Here, the abovementioned Y-axis is defined as
propagation axis (or transmission axis), and light

transmitting through the reflection-type polarizing film has a first polarizing orientation (or direction of polarization).

5   On the other hand, light that has not transmitted through the reflection-type polarizing film is polarized light exhibiting a second orientation which intersects the first polarizing orientation at right angles. Light exhibiting such a polarizing orientation is incident on the plane of
10   the film along the X-axis and is reflected by the action of difference in the interlayer refractive index. Therefore, the X-axis is defined to be a reflection axis. In such a state, the reflection-type polarizing film permits the transmission of only light having a selected polarizing
15   orientation (or direction of polarization).

      Optical properties (reflection property and transmission property) of the reflection-type polarizing film vary, usually, depending upon the optical thicknesses of various
20   polymer layers constituting the reflection-type polarizing film. If these polymer layers have optical thicknesses corresponding to a plurality of wavelengths of light or, in other words, represented by such wavelengths, then, the optical properties specifically and effectively respond in
25   the band (wavelength band). If these layers have optical thicknesses smaller than the wavelengths of light, then, the structural interference can be utilized for improving the optical performance of the reflection-type polarizing film in the selected wavelengths.
30

      A uniform layer having an optical thickness smaller than the wavelength of light of a visible spectrum can be formed by methods described in the working examples appearing later. When the thickness of the pair of layers "A" and "B"

is greater than one-half the wavelength of incident light (A
+ B > $\lambda'/2$), structural interference takes place. Depending
upon the half-wavelength condition, there takes place
structural interference of a narrow band at a predetermined
5   wavelength. Optical performance of a wide band can be
obtained by laminating or bonding a plurality of polymer
layers of narrow bands. For instance, a first group of
polymer layers having an equal thickness (A + B = $\lambda/2$) can
be laminated on a second group of polymer layers having a
10 dissimilar thickness (A + B = $\lambda'/2$). Usually, several
hundreds of polymer layers (--- A B A B ---) can be
laminated or bonded integrally together to obtain an
effective response over a wide band. It is desired that the
reflectiontype polarizing film is designed to reflect light
15 at any desired angle of incidence and at any wavelength.

Usually, the reflection factor of the reflection-type
polarizing film is preferably less than 20%, more
preferably, less than 10% and, most preferably, less than
20 5%, with respect to light linearly polarized in a direction
in parallel with the Y-axis. The reflection factor is an
average value for a desired zone of wavelengths and for a
desired zone of angles of incidence for particular or
general use. The reflection factor of the reflection-type
25 polarizing film for linearly polarized light along the X-
axis should preferably be not smaller than 30% and, more
preferably, not smaller than 60% at a desired maximum angle
of incidence.

30 The reflection-type polarizing film can be obtained by
preparing a web containing the above-mentioned polymer
layers alternatingly laminated like --- A B A B ---
according to a customary method of preparing a multi-layer
film followed by drawing. As required, furthermore, a third

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polymer, a fourth polymer, and subsequent polymers may be used in addition to the first polymer "A" and the second polymer "B", thereby to form a polarizing film containing these polymer layers. When three or more kinds of polymers

5 are to be used in combination, the order of laminating the polymer layers can be variously changed depending upon the desired effect.

Though not necessarily limited to those described below,

10 typical examples of the polymer material that can be suitably used for forming the reflection-type polarizing film include isomers of polyethylene naphthalate (PEN) such as 2,6-, 1,4-, 1,5-, 2,7- and 2,3-PENs; polyalkylene terephthalates such as polyethylene terephthalate,

15 polybutylene terephthalate, poly-1,4cyclohexanedimethylene terephthalate; polyimides such as polyacrylimides, polyetherimides; polystyrenes such as atactic polystyrene; polycarbonates; polymethacrylates such as polyisobutyl methacrylate, polypropyl methacrylate, polyethyl

20 methacrylate and polymethyl methacrylate; polyacrylates such as polybutyl acrylate and polymethyl acrylate; cellulose derivatives such as ethyl cellulose, cellulose acetate, cellulose propionate, cellulose acetate butylate and cellulose nitrate; polyalkylene polymers such as

25 polyethylene propylene, polybutylene, po lyisobutylene, poly(4-methylpentene); fluorinated polymers such as perfluoroalkoxy resin, polytetrafluoroethylene, fluorinated ethylene/propylene copolymer, polyvinylidene fluoride, polychlorotrifluoroethylene; chlorinated polymers

30 such as polyvinylidene chloride, polyvinyl chloride; polysulfones; polyethersulfones; polyacrylonitrile; polyamides; silicone resin; epoxy resin; polyvinyl acetate; polyether amides; ionomer resin; elastomers such as

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polybutadiene, polyisoprene, neoprene; polyurethanes; and the like.

Furthermore, as the polymer material, a copolymer can be
similarly and advantageously used instead of the above-mentioned polymers or in combination therewith. The copolymer that can be used herein may be a two-component copolymer, a three-component copolymer or any other copolymer. Preferred examples of the copolymer include:

(1) a copolymer of polyethylene naphthalate (PEN) such as a copolymerized polyester (so-called copolyester) synthesized, for example, from a 2,6-, 1,4-, 1,5-, 2,7-and/or 2,3 naphthalenedicarboxylic acid or an ester of any one thereof;

two or more acids selected from the group consisting of (a) terephthalic acid or esters thereof, (b) isophthalic acid or esters thereof, (c) phthalic acid or esters thereof, (d) alkanedicarboxylic acid, and (e) cycloalkanedicarboxylic acid (such as cyclohexanedicarboxylic acid); and

one or two or more glycols selected from the group consisting of alkane glycols and/or cycloalkane glycols (e.g., cyclohexanedimethanol diol);

(2) a copolymer of polyalkylene terephthalate such as a copolymerized polyester synthesized, for example, from two or more acids selected from the group consisting of (a) terephthalic acid or esters thereof, (b) isophthalic acid or esters thereof, (c) phthalic acid or esters thereof, (d) alkanedicarboxylic acid, and (e) cycloalkanedicarboxylic acid (such as cyclohexanedicarboxylic acid); and

one or two or more glycols selected from the group consisting of alkane glycols and/or cycloalkane glycols (such as cyclohexanedimethanol diol); and

(3) a copolymer of styrene, such as styrene/butadiene copolymer, styrene/acrylonitrile copolymer, etc.

In the reflection-type polarizing film, the polymer
layers constituting the polarizing film may contain the
above-mentioned polymer or copolymer solely, or may contain

5   two or more kinds of the polymers and/or copolymers in any
combination as a blend.

The polymer layers constituting the polarizing film have
thicknesses that can be widely changed depending upon the

10 desired polarizing effect but usually from about 0.01 to
0.70 µm. When such polymer layers are laminated in many
number to form a polarizing film, the polymer layers are
laminated in a number as small as possible to heighten the
transmission of light and to obtain desired optical

15 characteristics. The number of the polymer layers laminated
in the polarizing film is usually less than 5,000,
preferably, less than 1,000 and, more preferably, from 100
to 500.

20 Moreover, the thickness of the polarizing film can be
widely changed depending upon the desired polarizing effect
and the number of the polymer layers that are laminated, but
is usually from about 0.5 µm to 0.5 mm.

25 Furthermore, the polymeric multi-layer polarizer of the
present invention may contain additives such as ultraviolet
rayabsorbing agent, anti-oxidizing agent, anti-molding
agent, antirusting agent, moisture-absorbing agent, coloring
material, phosphorescent material, surfactant and the like

30 to such a degree that they do not impair the effect of the
invention.

Furthermore, a light-transmitting protection film may be
formed on the front surface, on the back surface or on both

surfaces of the polarizer so far as it does not impair the
effect of the present invention.

5   In the-polymeric multi-layer polarizer, the individual
layers are made of a polymeric material having
birefringence. Therefore, a linearly polarized light having
a particularly polarized direction may be allowed to pass
through thereby to reflect the linearly polarized light that
intersects therewith at right angles. Since the polymeric
10   material does not almost absorb light, loss is very small
for the linearly polarized light that transmits
therethrough.

         According to a preferred embodiment of the present
15   invention, the Faraday rotator to be sandwiched by the first
and second polarizers is made up of a 45° Faraday rotator
capable of rotating the polarizing plane by 45 degrees. in
this case, a tapered glass plate is simultaneously used
between the Faraday rotator and the second polarizer. The
20   451 Faraday rotator may have a constitution which is
generally employed in this field of art and is formed of a
thick film of, for example, Bi-substituted rare earth Fe
garnet, such as GdBiFe garnet. The tapered glass plate is
usually formed of a glass having a refractive index of from
25   about 1.45 to 1.65, such as borosilicate glass. The tapered
degree may vary depending upon the optical system in which
the optical isolator is used and the desired effect, but is
usually from 0.2 to 3°.

30   In another preferred embodiment of the present invention,
the Faraday rotator is made up of a tapered Faraday rotator.
The tapered Faraday rotator may have a constitution which is
generally employed in this field of art and is formed of a
thick film of, for example, Bi-substituted rare earth Fe

garnet, such as GdBiFe garnet. The tapered degree of the
tapered Faraday rotator may vary depending upon the optical
system in which the optical isolator is used and the desired
effect, but is usually from about 0.2 to 3°.

5

   In the optical isolator of the present invention, it is
desired that the constituent elements such as Faraday
rotator and polarizers are secured integrally together and,
particularly, joined together with an adhesive. Though

10 there is no particular limitation, the adhesive used here
should advantageously be the one having high degree of
transparency and excellent adhering force. The light
transmission factor of the adhesive used herein is usually
not lower than 70%, preferably, not lower than 80% and, more

15 preferably, not lower than 85%.

   As such highly transparent adhesive, an acrylic adhesive
is preferably used having a high degree of transparency and
a large adhering force. The acrylic adhesive is a polymer

20 obtained from a reaction material containing an acrylate
monomer having an alkyl group with 4 to 14 carbon atoms,
such as isooctyl acrylate, butyl acrylate or 2-ethylhexyl
acrylate, and a (meth)acrylate monomer having a polar group,
such as (meth)acrylic acid, carboxylalkyl (meth)acrylate,

25 hydroxylalkyl (meth)acrylate or N,N-dialkyl acrylamide, or a
composition containing such a polymer. As is widely known,
"(meth)acrylic acid" is a term which encompasses acrylic
acid and methacrylic acid, and (meth)acrylate and the like
are used accordingly.

30

   To adhere the elements by using an acrylic adhesive or
any other adhesive, the adhesive is applied to the surface
of the one element to form a layer of the adhesive, and this
element with the adhesive layer is press-adhered to another

element. The adhesive layer has a thickness of, usually,
from 5 to 100 [im and, preferably, from 10 to 50 μm. The
adhesive layer is formed by, for example, applying a coating
solution containing the above mentioned polymer or polymer
5   composition onto the element. The polymerization may be
carried out on the element after the coating solution
containing the above-mentioned reaction material is applied
thereon. Or, a film-like adhesive formed on a separate
peeling film may be transferred onto the element from the
10   peeling film. The adhesive layer may contain the
abovementioned various additives so far as the transparency
is not impaired.

     In the optical isolator of the present invention, two
15   polymeric polarizers having a direction of polarization of
transmitted light of 45 degrees with respect to the linearly
polarized light are arranged in front of, and at the back
of, the Faraday rotator to obtain a large loss in the
reverse direction. That is, the loss of the thus
20   constituted optical isolator in the reverse direction varies
depending upon the light-extinguishing ratio of the
polarizers, dependency of Faraday rotational angle upon the
wavelength of light and upon the temperature. However, the
polymeric polarizer used in the present invention reflects
25   light that has not transmitted and guides the reflected
light out of the optical system, making it possible to
obtain a large loss in the reverse direction.

     Working examples of the present invention will now be
30   described in detail with reference to the accompanying
drawings. Here, however, it should be noted that the
present invention is in no way limited to the following
examples only.

Example 1

Figure 1 is a sectional view illustrating an optical
isolator according to the first example of the present
invention.   In the diagramed optical isolator 10, a first
polarizer 1 and a second polarizer 2 are those of the
reflection type composed of the above-mentioned polymeric
multi-layer film, and have been so set that the directions
of polarization of light that has transmitted through the
polarizing plates define an angle of 45° degrees relative to
each other.   The polarizing plates have a thickness of about
0.1 mm, respectively.   Between these two pieces of
polarizing plates are arranged a 45° Faraday rotator 3 made
of a thick film of GdBiFe garnet and a tapered glass plate 4
in a manner as shown.   To the 45° Faraday rotator 3 is
applied a magnetic field H along a direction in which light
travels.   The tapered glass plate 4 has a refractive index
of 1.55 and a tapered angle of 2 degrees.   Furthermore,
though not shown, the elements are joined and secured
together with an acrylic adhesive (isooctyl acrylate/acrylic
acid copolymer, light transmission factor of about 98%).

The principle of operation of the shown optical isolator
10 will be described below with reference to a sectional
view of Fig. 2 which illustrates the optical paths of the
optical isolator in the forward direction and in the reverse
direction.   First, light L, incident on the optical isolator
10 from the forward direction passes through the first
polarizer 1, 45° Faraday rotator 3, tapered glass plate 4,
and second polarizer 2, successively, and goes out in the
direction of optical path L2' Here, light is refracted to
some extent depending upon the ratio of a refractive index
of the adhesive joining the elements and a refractive index
of the air surrounding the optical isolator 10.

On the other hand, a polarized light component of light L_2 incident on the optical isolator 10 from the reverse direction (from the right side in Fig. 2) is reflected in

5   the direction of optical path L_3 by the second polarizer 2. The polarized light component that is not reflected but has transmitted through the second polarizer 2, passes through the tapered glass plate 4 and 45° Faraday rotator 3, successively, and falls on the first polarizer 1. Here, the

10   direction of polarization of the polarizer 1 has been turned by 90 degrees from the direction of transmission of the polarizer. Therefore, light incident on the polarizer 1 is reflected again, passes through the Faraday rotator 3 and tapered glass plate 4, and arrives at the polarizer 2. In

15   the polarizer 2, the direction of polarization of the incident light has been turned by 90 degrees from the direction of transmission of the polarizer 2, and, hence, the incident light is reflected. Next, the reflected light passes through the tapered glass plate 4 and Faraday rotator

20   3, and falls on the polarizer 1. Here, however, the direction of the reflected light is in agreement with the direction of transmission of the polarizer 1. Therefore, light transmits in the direction of optical path L_4. When compared with the direction L_1 of incidence of light from the

25   forward direction, the traveling direction L_4 of light is tilted by an angle nearly equal to the product of twice the tapered angle of the tapered glass plate 4 and the refractive index of the adhesive. That is, in the optical system in which the diagramed optical isolator 10 is

30   disposed, the incident light from the reverse direction is never coupled to the optical path of incident light from the forward direction.

Figure 3 is a graph illustrating the above-mentioned
behaviour. In this graph have been plotted optical
characteristics of when the optical isolator 10 of Fig. 1 is
arranged in the optical system of parallel light beam, and
5   wherein a curve I represents loss of light in the forward
direction and a curve II represents loss of light in the
backward direction. When the wavelength is, for example,
1,550 nm, the loss in the forward direction is about 0.34 dB
and the loss in the backward direction is about 41 dB. This
10   result indicates that the diagramed optical isolator 10
makes it possible to accomplish a markedly large loss in the
reverse direction owing to its constitution.

When compared with the conventional optical isolator, the
15   optical isolator 10 of Fig. 1 can be easily produced through
a very simple process of production maintaining good yield
of products. That is, since the individual constituent
elements are stuck with an adhesive and are secured
together, a number of optical isolators can be correctly
20   produced at one time contributing greatly to decreasing the
cost of production and increasing the yield. For example,
when the Faraday rotator, tapered glass plate and two pieces
of polarizing plates of a square shape having a side
measuring 11 mm are adhered and are, then, cut, there can be
25   obtained a total of 25 optical isolators (each having a
square shape with its side measuring 1.7 *mm)*.

Example 2

30   Figure 4 is a sectional view illustrating the optical
isolator according to the second example of the present
invention. In the diagramed optical isolator 10, the first
polarizer 1 and the second polarizer 2 are reflection-type
polarizing plates made of the polymeric multi-layer film

same as the one used in the above-mentioned Example 1, which
are so set that the directions of polarization of light that
has transmitted through the polarizing plates define an
angle of 45 degrees relative to each other. Between these

5   two polarizers is sandwiched a tapered Faraday rotator 5
made of a thick film of GdBiFe garnet in a manner as shown.
To the Faraday rotator 5 is applied a magnetic field H along
the direction in which light travels. The tapered angle of
the Faraday rotator 5 is 2 degrees. Though not shown, the

10   individual elements are joined and secured together with an
acrylic adhesive (isooctyl acrylate/acrylic acid copolymer,
light transmission factor of about 98%). Furthermore, non-
reflection coating has been applied to the surfaces of the
first polarizer 1 and of the second polarizer 2 that are

15   exposed to the air. A non-reflection coating for the
adhesive has also been applied to both surfaces of the
Faraday rotator 5.

In the illustrated optical isolator 10, the Faraday

20   rotator 5 is tapered. Accordingly, Faraday rotational angle
can be varied depending upon the distance from the center
axis 11 of the optical isolator 10 for the transmitted
tight. in the optical system in which the optical isolator
is disposed, however, the required tapered angle is usually

25   from about 1 to about 2 degrees. With the tapered angle of
this degree, a thick film of Bi-substituted rare earth Fe
garnet in which the Faraday rotator has an average thickness
of about 0.4 mm, makes it possible to obtain a large loss of
not smaller than 25 dB in the reverse direction when the

30   diameter of light beam is 1 mm.

In the optical isolator of the type shown, when a thick
film of Bi-substituted rare earth Fe garnet that does not
require an external magnetic field is used as a Faraday

rotator, there is realized a small optical isolator since the polarizer has a thickness of about 0.1 mm. Besides, the optical isolators can be produced at one time and at a low cost.

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When the 45° Faraday rotator has a thickness of not smaller than 1.5 mm, furthermore, a change in the Faraday rotational angle in the light transmission plane can be neglected in, for example, the Bi-substituted rare earth

10 garnet thick film in which priority is given to the wavelength dependency and in the CdMnMgTeSe crystal, and an improved isolation is accomplished.

According to the present invention, as will be appreciated

15 from the above descriptions, in the optical isolator in which the Faraday rotator is sandwiched by two polarizers as described above, the polarizers that are used feature large areas without requiring such work as polishing. Besides, use of such polarizers makes it possible to mass-produce

20 optical isolators through easy and simple manufacturing process while reducing the cost of production.

CLAIMS

1. An optical isolator comprising:

   a first reflection-type polarizer made of a polymeric
5   multilayer film;

   a Faraday rotator capable of rotating a polarizing plane
   by 45 degrees;

   a tapered glass plate; and

   a second reflection-type polarizer made of a polymeric
10   multi-layer film, the first reflection type polarizer,
   the Faraday rotator, the glass plate and the second
   reflection-type polarizer being optically aligned in
   order.

15 2.   An optical isolator according to claim 1, wherein said
   first polarizer, Faraday rotator, glass place and second
   polarizer elements are joined together with an adhesive.

   3.   The optical isolator od claim 1, wherein the first and
20 the second reflection-type polarizers comprise birefringent
   multilayer polarizing film.

   4.   The optical isolator of claim 2, the adhesive
   comprising a highly transparent acrylic adhesive.
25

   5.   The optical isolator of claim 1, the first and second
   polarizers having a direction of polarization of 45 degrees
   with respect to linearly polarized light.

30 6.   An optical isolator comprising the following elements
   in the described order:

   a first reflection-type polarizer made of a polymeric
   multilayer film;

   a tapered Faraday rotator; and

a second reflection-type polarizer made of a polymeric
multi-layer film.

7. An optical isolator according to claim 3, wherein said
elements are joined together with an adhesive.

8. A method for manufacturing an optical isolator
comprising the steps of:

    a)   providing a first and a second polymeric multi-
layer film polarizer, each polarizer having a
direction of polarization;

    b)   arrange the first and second polarizers such that
the directions of polarization of each polarizer
are at a 45 degree angle relative to each other;

    c)   place a 45° Faraday rotator optically between the
first and second polarizer.

9. The method of claim 8, wherein the Faraday rotator is a
tapered Faraday rotator.

10. The method of claim 8, wherein the Faraday rotator
comprises a film of GdBiFe garnet and a tapered glass plate.

11. The method of claim 8, further comprising the step of
joining the first and second polarizer to the Faraday
converter using an adhesive.

AMENDED CLAIMS

[received by the International Bureau on 06 March 2000 (06.03.00);
original claims 1,2,3,5,7 and 8 amended; new claims 12 and 13 added;
remaining claims unchanged (2 pages)]

1. An optical isolator (10) comprising:

    a first reflection-type polarizer (1) made of a polymeric

5   multilayer film;

    a Faraday rotator (3);

    a glass plate (4); and

    a second reflection-type polarizer (2) made of a
    polymeric multi-layer film, the first reflection type

10 polarizer, the Faraday rotator, the glass plate and the
    second reflection-type polarizer being optically
    aligned in order.

2.   An optical isolator according to claim 1 or 3, wherein
15 said first polarizer, Faraday rotator, glass place and
    second polarizer elements are joined together with an
    adhesive.

3.   The optical isolator of claim 1, wherein the first and
20 the second reflection-type polarizers comprise birefringent
    multilayer polarizing film.

4.   The optical isolator of claim 2, the adhesive
    comprising a highly transparent acrylic adhesive.

25

5.   The optical isolator of any one of claims 1 to 4, the
    first and second polarizers having a direction of
    polarization of 45 degrees with respect to linearly
    polarized light.

30

6.   An optical isolator comprising the following elements
    in the described order:

        a first reflection-type polarizer made of a polymeric
        multilayer film;

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a tapered Faraday rotator; and

a second reflection-type polarizer made of a polymeric
multi-layer film.

7. An optical isolator according to claim 6, wherein said
elements are joined together with an adhesive.

8. A method for manufacturing an optical isolator (10)
comprising the steps of:

a)   providing a first and a second polymeric multi-
layer film polarizer (1, 2), each polarizer having
a direction of polarization;

b)   arrange the first and second polarizers such that
the directions of polarization of each polarizer
are at a 45 degree angle relative to each other;

c)   place a 45° Faraday rotator (3) optically between
the first and second polarizer.

9. The method of claim 8, wherein the Faraday rotator is a
tapered Faraday rotator.

10. The method of claim 8, wherein the Faraday rotator
comprises a film of GdBiFe garnet and a tapered glass plate.

11. The method of claim 8, further comprising the step of
joining the first and second polarizer to the Faraday
converter using an adhesive.

12. The optical isolator of any one of claims 1-5, wherein
the glass plate is tapered.

13. The optical isolator of any one of claims 1-5 or 12,
wherein the Faraday rotator is capable of rotating a
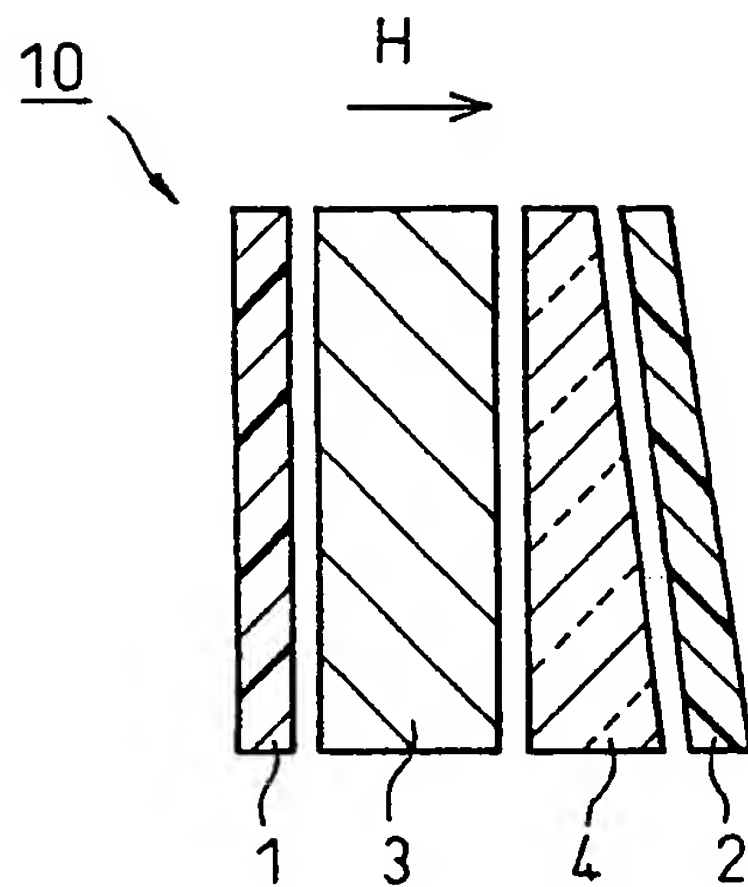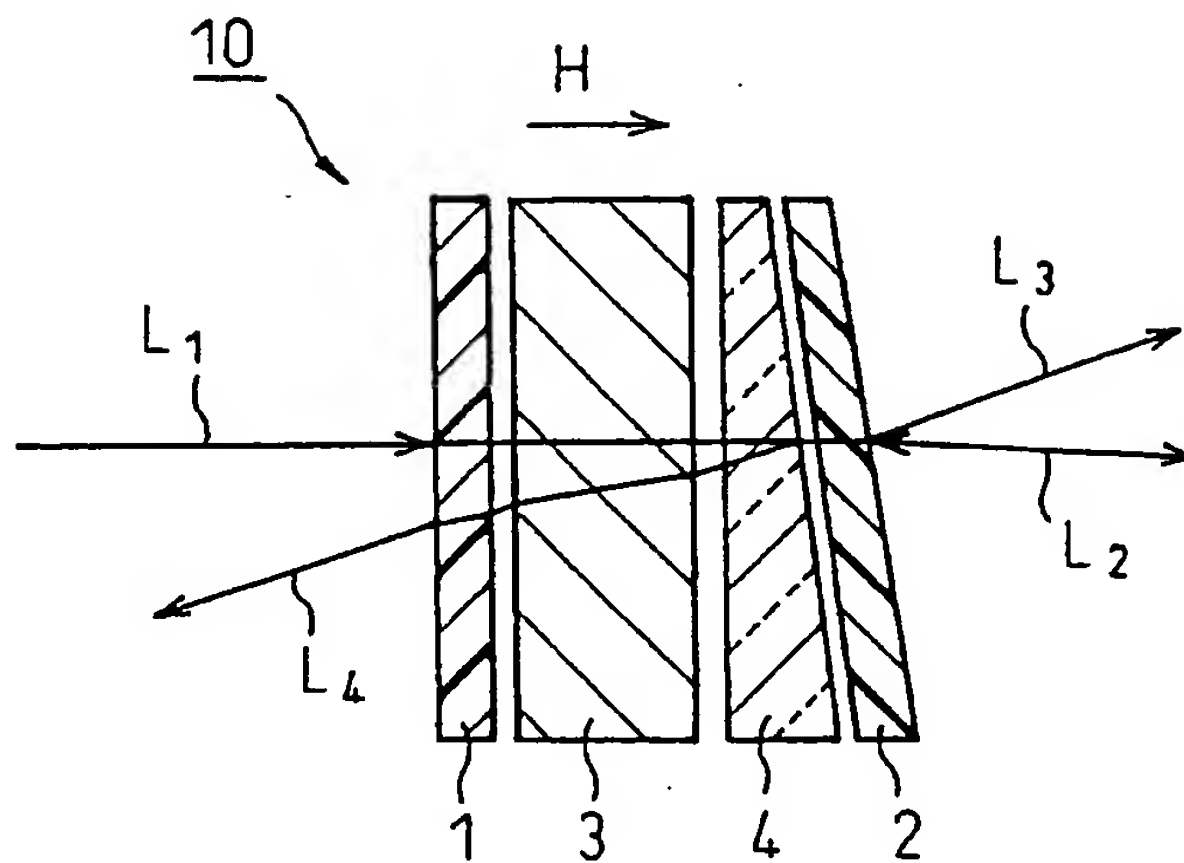polarizing plane by 45 degrees.

22

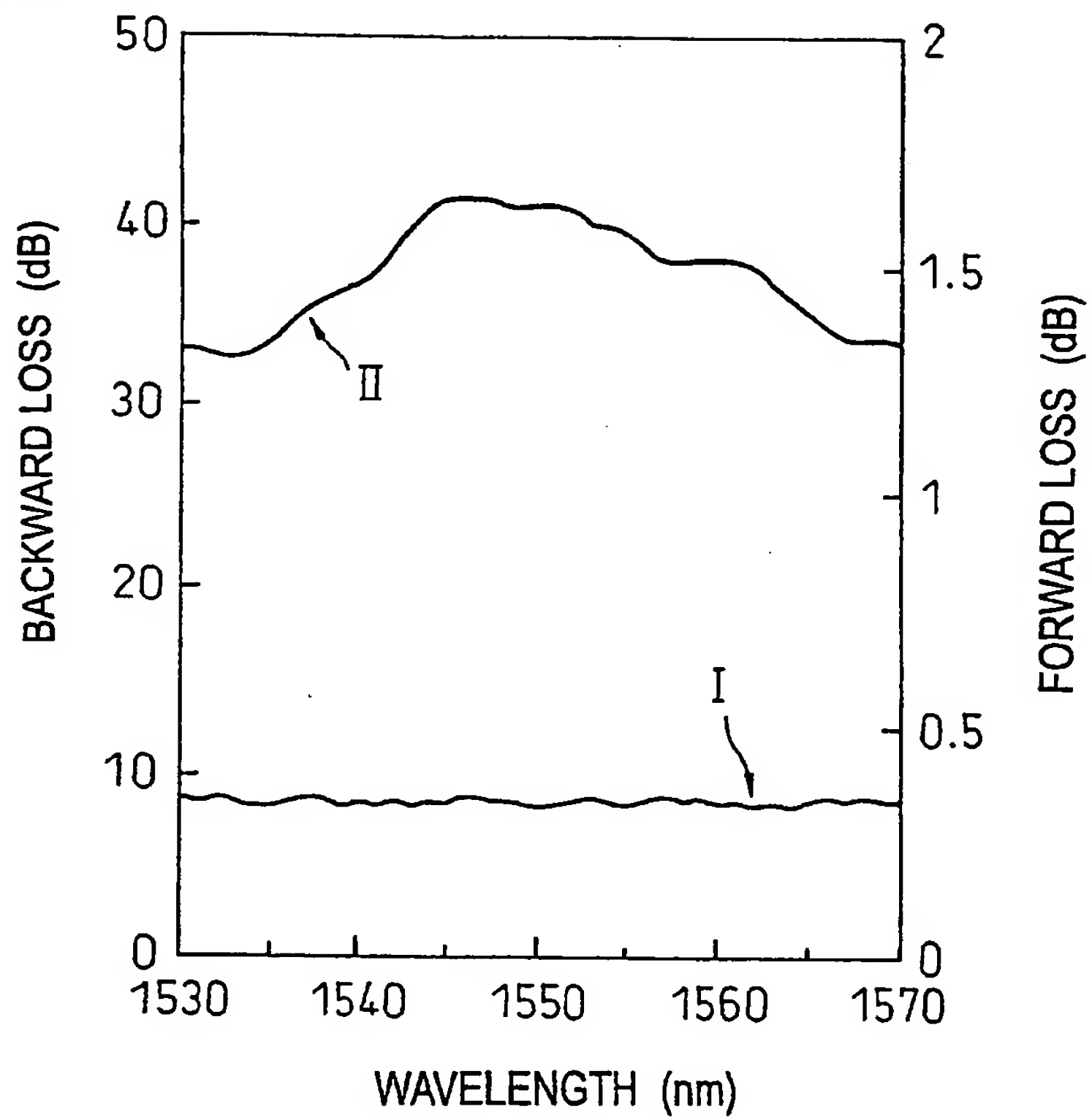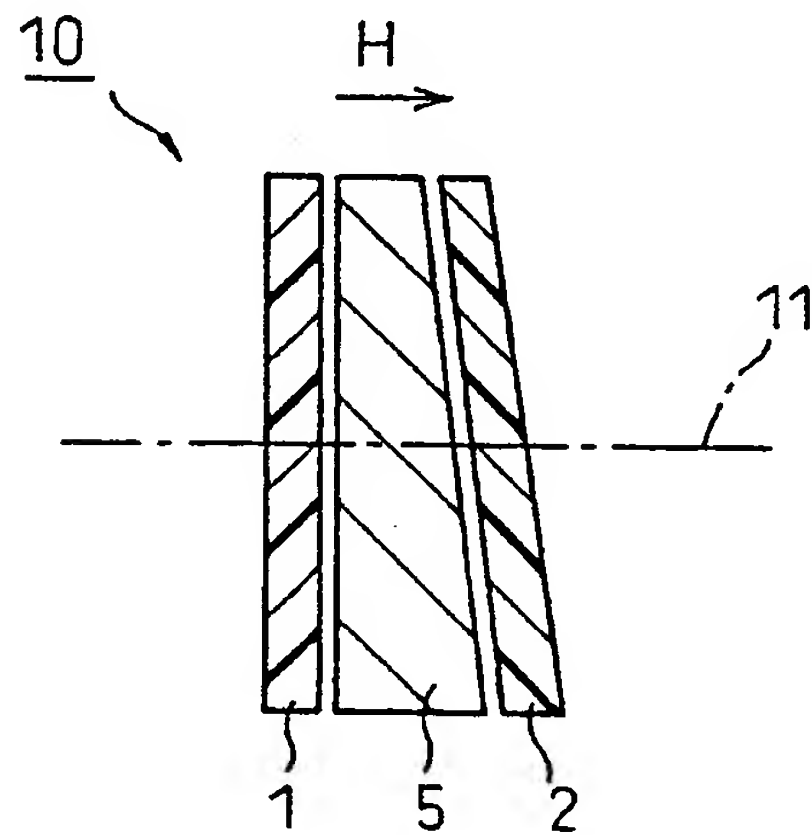AMENDED SHEET (ARTICLE 19)

Fig .1

Fig .2

Fig .3

Fig .4

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7   G02F1/09   G02B6/26

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7   G02F   G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate. of the relevant passages	Relevant to claim No.
Y	GB 2 173 607 A (FUTABA DENSHI KOGYO KK) 15 October 1986 (1986-10-15)	8
A	page 1, line 39 - line 74 page 3, line 24 - line 44; figures 1,7 ---	1,5,6
Y	WO 95 17691 A (MINNESOTA MINING & MFG) 29 June 1995 (1995-06-29)	8
A	page 2 & JP 09 507308 T cited in the application ---	1,3,6
A	US 5 574 595 A (KURATA NOBORU ET AL) 12 November 1996 (1996-11-12) column 5, line 15 - line 30; figure 1 ---	1,6,8

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| X | Further documents are listed in the continuation of box C. |
| X | Patent family members are listed in annex. |

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 December 1999	14/01/2000

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INTERNATIONAL SEARCH REPORT

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category[3]	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	PATENT ABSTRACTS OF JAPAN vol. 008, no. 245 (P-312), 10 November 1984 (1984-11-10) & JP 59 119315 A (FUJI DENKI KAGAKU KK), 10 July 1984 (1984-07-10) abstract ---	8
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